



Thermal Testing of Woven TPS Materials in Extreme Entry Environments

G. Gonzales[§], M. Stackpoole^{*}

[§] ERC Inc., Moffett Field, CA 94035, ^{*} NASA Ames Research Center, Moffett Field CA 94035

Introduction

The Heatshield for Extreme Entry Environment (HEET) Project is funded by NASA's Space Technology Mission Directorate under the Game Changing Development Program (GCDP).

HEET seeks to mature a novel Woven Thermal Protection System (TPS) technology to enable in-situ robotic science missions recommended by the NASA Research Council Planetary Science Decadal Survey committee as outlined in Figure 1.

Recommended science missions include Venus probes and landers, Saturn and Uranus probes, and high speed sample return missions.

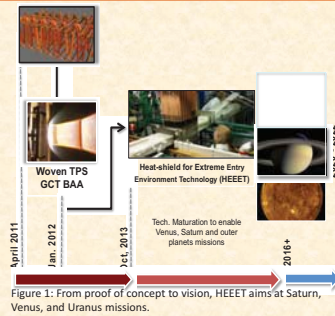


Figure 1: From proof of concept to vision, HEET aims at Saturn, Venus, and Uranus missions.

Woven TPS – The Concept

Woven TPS leverages the mature weaving technology that has evolved from the textile industry to design TPS with tailorable performance by varying the material composition and properties while controlling placement of fibers within a woven structure

The resulting woven TPS can be **designed and tailored** to perform optimally for a wide range of entry environments without substantially changing the manufacturing and certification process

The woven TPS approach utilizes commercially available weavers, using equipment, modeling and design tools to optimize the weave. This allows for the control of material composition and density resulting in tailored performance - by leveraging this technology NASA will not be burdened with maintaining the capability or having to accept the risk for material restart

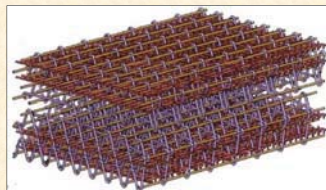


Figure 2: Weave architecture: schematic of one possible configuration.

Woven TPS approach allows design and manufacture of **ablative** TPS materials by specific placement of fibers in a 3D woven structure illustrated in Figure 2

Weaving flexibility allows :

- Ability to design TPS to meet specific mission needs
- Tailoring composition by weaving together different fiber types (carbon, glass, polymer, other)
- Tailoring density

Arc Jet Test Objectives

The purpose of these test series is to evaluate the behavior of HEET material performance in high/extreme entry conditions in current ground based testing facilities.

The IHF and AEDC facilities have recently been upgraded to expand their testable envelope and testing at these higher conditions will be presented. Additionally, comparisons to heritage chop molded carbon phenolic (CMCP) and tape-wrapped carbon phenolic (TWCP) will be presented. Test conditions and example mission conditions are outlined in Figure 3.

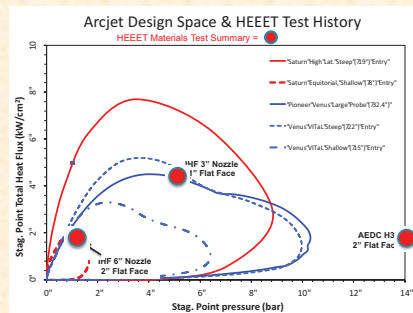


Figure 3: Design space for mission entry conditions for Saturn and Venus and test conditions history for arcjet facilities.

Testing in Ames Arc Jet Facility (IHF with 6\"/>

Test Purpose:

- Evaluate the 3D woven HEET TPS material in a simulated entry environment at heat fluxes approaching 1700 W/cm². TPS coupons had a 2-inch diameter flat face geometry.
- Primary objectives of this test series were:
 - Demonstrate applicability of 3D Woven ablator concepts at high heat flux conditions: 1680 W/cm² actual – (cold wall) and ~1.3 atm stagnation
 - Compare performance to heritage-like carbon phenolic materials

Figure 4 illustrates the model assembly used in this test series. TPS stagnation models were mounted to a graphite adapter. Test articles were instrumented with one backface TC, inserted through the center of the model.

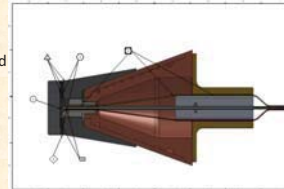


Figure 4: Model build for IHF 6\"/>

Table I - Heating environment for IHF 2-inch flat face stagnation models as measured on a 2-inch flat face calorimeter.

| Cold wall Heat Flux 2-in flat face (W/cm ²) | Stagnation Pressure (atm) | Shear (Pa) |
|---|---------------------------|------------|
| 1680 | 1.3 | 0 |

Images of pre- and post-test specimens are shown in Figure 5. All ablated uniformly and did not exhibit any unusual failure modes. The HEET materials performed well. The post-test images do not indicate any unusual features on the test surface. Carbon phenolic was also tested and behaved in a controlled manner. Some delamination of the chopped material was observed in the CMCP material.



Figure 5: HEET material (left), TWCP-20 degree (mid.), and CMCP (right). Pre test images on top, Post test images on the bottom.

Testing in Ames Arc Jet Facility (IHF 3\"/>

Test Purpose:

- Evaluate the HEET TPS at extreme heat flux conditions, ~5000 W/cm² (cold wall) and ~5 atm. TPS coupons had a 1-inch diameter flat face geometry as diagramed in Figure 6. Figure 7 shows pre and post-test images.
- Primary objectives of this test series were:
 - Demonstrate applicability of 3D Woven ablator concepts developed under the Woven TPS project at extreme heat flux/pressure.

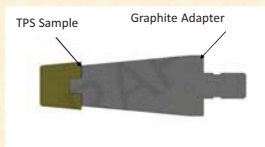


Figure 6: Model design for 3\"/>

Table 1 – CFD calculated heating environment on 1-inch flat face model.

| CW Heat Flux 1-in flat face (W/cm ²) | Stagnation Pressure (atm) | Shear (Pa) |
|--|---------------------------|------------|
| 4800 | 6 | 0 |

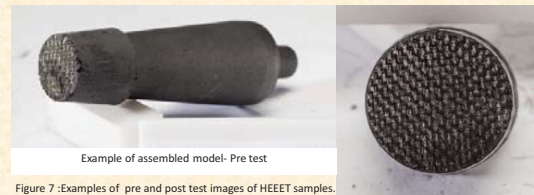


Figure 7: Examples of pre and post test images of HEET samples.

All samples evaluated ablated uniformly with no unusual failure modes developed.

Testing at AEDC Facility (H3)

Test Purpose:

- Evaluate the 3D woven HEET down-selected architecture in a turbulent heating environment under extreme stagnation pressure, 14 atm and ~1850 W/cm²
- Primary objectives of this test series was:
 - Demonstrate applicability of HEET composition at extreme pressure
 - Compare performance to heritage CMCP
- Figure 8 shows the model schematic. Each sample was attached to machined carbon phenolic model holder that was then attached to the facility sting arm.

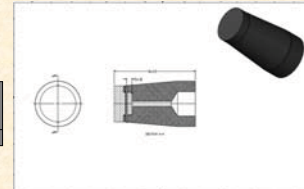


Figure 8: Model schematic of H3 testing at AEDC.

Table III - CFD calculated heating environment on AEDC 2-inch flat face model.

| CW Heat Flux 2-in Flat face (W/cm ²) | Stagnation Pressure (atm) | Shear (Pa) | Distance From Nozzle (in) |
|--|---------------------------|------------|---------------------------|
| 1850 | 14 | 0 | 3 |

Photographs of pre- and post-test are shown of the HEET acreage material (Figure 9) and CMCP (Figure 10)

The HEET material ablated very uniformly and did not exhibit any unusual failure modes. Due to the model conditions being more severe at the edges, and limitations in the thickness of material available, the insulating layer at the edges was exposed. In the future the recession layer would be sized to specific mission conditions and this flexibility is a benefit of this type of woven architecture.

Chop molded carbon phenolic was also tested. Some delamination of the chopped material was observed in the CMCP material and the final surface appears somewhat uneven as shown in Figure 10.



Figure 9: HEET acreage material pre-test and during test. Remaining recession layer in center of test area remains smooth despite higher recessions on edge.

Figure 10: CMCP pre and post-test images. Final surface is much rougher compared to HEET material.

Summary

Facility upgrades have widened the envelope for ground-based testing capabilities allowing more extreme conditions to be tested

HEET material performed well in all 3 test series.

No unexpected failure modes were observed

Heritage carbon phenolic materials were tested alongside HEET to make performance comparisons.

Based on these arcjet results in extreme entry environments, HEET woven material options are viable alternatives to heritage carbon phenolic.

Acknowledgements

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